Perceptual and Motor Skills, 1993, 77, 1059-1065. © Perceptual and Motor Skills 1993

GEOPHYSICAL VARIABLES AND BEHAVIOR: LXXIV. MAN-MADE FLUID INJECTIONS INTO THE CRUST AND REPORTS OF LUMINOUS PHENOMENA (UFO REPORTS)—IS THE STRAIN FIELD AN ASEISMICALLY PROPAGATING HYDROLOGICAL PULSE?[1]

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Summary.—According to the tectonic strain theory, both earthquakes and most reports of UFOs (Unidentified Flying Objects) or odd luminous phenomena are generated by local transient changes in regional crustal stress. Because the injection (or containment) of fluids or their percolation into the upper crust can trigger earthquakes, we predicted that reports of these anomalous luminous phenomena should display temporal lags and spatial diffusion around these sites. The hypothesis was supported around the five test sites of Derby, Colorado; Attica, New York; Rangely, Colorado; Sanford (Amarillo), Texas; and Hanford, Washington. The results support the hypothesis that luminous phenomena, often described by the contemporary label of UFOs, are associated with natural hydroseismicity and can be initiated by man-made activity.

There is compelling evidence that most verified reports of classical UFO (Unidentified Flying Object) episodes are generated by sightings of natural luminous phenomena that are coupled to geophysical processes. We (Derr & Persinger, 1986, 1989, 1990b; Persinger, 1976, 1990; Persinger & Derr, 1984, 1985) have hypothesized that these descriptions of odd lights or luminous phenomena are generated by transient (strain) changes within the regional and local fields of tectonic strain. Because earthquakes are also consequences of strain within geological structures, both luminous phenomena and earthquakes should be and are correlated temporally (Persinger, 1990). Empirical analyses have shown that luminous phenomena within a geological region primarily precede (by weeks to months) earthquakes and appear to accompany movements of strain fields.

Isolation of the mechanism would allow greater prediction of these phenomena and could encourage more reliable reporting by human observers; their epidemiological profile could be useful for the forecasting of seismic activity. Changes in the dilatancy of rock that is associated with alterations in groundwater is one likely candidate. Costain, Bollinger, and Speer (1987) have developed strong arguments that transient increases in fluid pressure are transmitted to depths of 10 km to 20 km where they trigger intraplate earthquakes. Both empirical and theoretical models (Gold & Soter, 1985; Roe-

[1]This research was partially supported by the Center for Mining and Mineral Exploration Research (CIMMER). Please send reprint requests to Dr. M. A. Persinger, Behavioral Neuroscience Laboratory or Department of Psychology, Laurentian University, Sudbury, Ontario, P3E 2C6 Canada.

loffs, 1988) indicate that if a permeable crust is tectonically stressed close to failure, relatively small amounts of fluid injection can enhance tectonic strain and trigger earthquakes.

If (1) earthquakes and luminous phenomena emerge from the same source of (tectonic strain) variance and (2) luminous phenomena represent less intense transient variations of strain that can permeate over larger areas, then luminous phenomena and hence numbers of UFO reports should (1) be temporally associated with man-made episodes of fluid injection (or forced artificial containment, e.g., crustal vaults) and (2) exhibit a time-dependent spatial diffusion away from the injection or containment site. Stated alternatively, if human activity (e.g., fluid injection or flooding of man-made lakes by dams) is of sufficient magnitude to activate the processes of tectonic strain from which luminous phenomena normally emerge, then they should be generated by this "cultural noise."

The occurrence of luminous phenomena in a geological basin within which fluid has been injected is not a new observation. For example, the persistent and periodic Marfa Lights (Texas) are adjacent to oil fields; until 1950, 80 million gallons of water were injected per day to extract crude petroleum. Today, near Balmorhea, tens of thousands of gallons are injected daily; increased seismic activity appears to have been related to petroleum production and water-flood projects near Kermit, Texas (Shurbet, 1969). Interestingly, the deposition of radioactive fluids into crustal vaults near the Hanford, Washington nuclear plant began in 1944, approximately three years before the series of observations that began the infamous 1947 UFO flap in the western portion of that state. These anecdotal observations suggest that the processes that generate luminous phenomena, although determined by tectonic stresses, can be affected by human activity that influences these same geophysical mechanisms.

Man-made injection or containment of fluids constitutes a variant of a "quasiexperimental" design that might test this hypothesis. We re-examined the Derby earthquake episode (Hsieh & Bredehoeft, 1981; Derr & Persinger, 1990a) and, as well, evaluated the injection periods at Rangely, Colorado and Attica, New York (Fletcher & Sykes, 1977). The containment intervals near Amarillo, Texas (Sanford Dam, filling of Lake Meredith) and Hanford, Washington (storage of radioactive fluids) (DOE, 1986) were also included. In each of these settings, fluid was injected into the earth's crust or stored in subterranean or surface bins. The estimated maximum fluid injections were at Derby 70 million gallons, at Hanford "millions" of gallons, and at Rangely 1.6 billion gallons. The consequence of pumping brine in Attica was evaluated by top-hole pressure (50 bars).

The numbers of general luminous phenomena per month as a function of both 50-km and 100-km radial increments (up to 300 km) from each of

the injection sites were determined from the data base supplied by the Center for UFO Studies (CUFOS); it contains the longitude, latitude, classification, and date (day, month, year) for each report. To minimize redundancies, no more than one report was accepted within the same day for the same location. All analyses were completed by SPSS software on a VAX 4000 computer.

As can be seen in Table 1, two clear patterns emerged. First, a significant increase in general luminous phenomena within 100 to 200 km from the site occurred about *two years* after the injection or containment of the major volumes of fluid began unless these sites had a history of fluid containment, i.e., Hanford and Derby. Secondly, the increase in general luminous phenomena at greater distances (100—200 km) from the injection site lagged behind the initial major increase in general luminous phenomena closest (0 to 100 km) to the injection site. This pattern would be compatible with a diffusion process.

To discern the approximate speed of this diffusion, the major episodes (2 for Attica, 2 for Rangely, 1 for Sanford, and 4 for Derby) of luminous phenomena (median numbers = 12/episode; range 4 to 15) for the four sites were identified since they involved specific dates. An episode was defined as any successive series of months that contained at least one general luminous phenomenon within 300 km from the site. Regressions were then completed between the numbers of luminous phenomena per 50-km radial increment (total of 6, i.e., 300 km) from the injection site as a function of time in months. The slopes were then estimated.

The average duration of the episodes was 6 months (range: 3 to 9 months). All of the correlations were positive (range 0.48 to 0.95), although only six were statistically significant ($p < .05$). These results indicated a gradual increase in distance between luminous phenomena sightings from the injection or containment site over time and support the diffusion model. The average slope for all three areas was 0.85. Stated alternatively, the successive increase in distance of the sightings of luminous phenomena from the radial increments closest to the injection sites occurred at about 45 km/month. If one removes those episodes where the number of cases were fewer than 5, then the average slope was 0.63 (about 30 km/month).

The concept of a diffusion gradient also demands that the actual rate of expansion should decrease as the distance from the injection site increases (Fink's law). Support for this hypothesis was noted graphically for the Rangely, Sanford, and Attica episodes. Contemporary association (same month) between luminous phenomena and injection volume occurred closest (<50 km) to the injection site but larger, more protracted lags were evident at greater distances (>100 km); this pattern was stronger and empirically evident for the Derby episode (Derr & Persinger, 1990a).

TABLE 1

DISTANCES (100-KM RADIAL INCREMENTS) FROM FLUID INJECTION SITES AND NUMBERS OF GENERAL LUMINOUS PHENOMENA PER YEAR*

Year	0—100 km	101—200 km	201—300 km
	Attica, New York		
1970	0	1	1
1971*	2	1	0
1972	2	0	0
1973	17	1	0
1974	8	4	2
1975	4	5	0
1976	1	3	1
	Rangely, Colorado		
1962	0	1	0
1963	0	0	0
1964	0	0	4
1965*	1	2	1
1966	3	1	0
1967	5	11	4
1968	2	2	0
1969	0	0	0
1970	0	0	0
	Derby, Colorado		
1962*	11	3	3
1963	5	0	2
1964	9	5	3
1965*	21	10	3
1966	20	24	3
1967	86	30	31
1968	6	6	5
1969	8	0	0
1970	1	0	0
	Hanford, Washington		
1950	5	1	22
1951	0	0	3
1952*	17	12	30
1953	0	5	3
1954	8	6	13
1955	7	8	22
1956	0	2	23
	Lake Meredith (Sanford Dam), Texas		
1963	1	1	1
1964	0	3	8
1965*	7	1	5
1966	4	4	3
1967	0	34	11
1968	1	6	5

*Year of commencement of injection or filling of reservoirs.

For all sites the occurrence of luminous phenomena at the greatest distances (>150 km) occurred within ± 1 year of the month that contained the greatest release of seismic energy for that period and region. For example, 81% of the luminous phenomena within the Uinta Basin occurred during the period between 9 months before and 9 months after the single event that released more than 90% of the seismic energy. If the release of seismic energy as an earthquake indicates that near-failure stress had been present regionally, then hydraulic anomalies could have been propagated over larger distances. The fact that some luminous phenomena occurred after the seismic release does not necessarily indicate an absence of near-fracture stress since even moderate (5.5 mb) earthquakes reduce the background stress of thousands of bars by only a few tens of bars.

The results also suggested a "dose-dependent" or magnitude-of-volume injection effect for the distance of involvement. For the Derby episode, where 70 million gallons per year were injected, statistically significant correlations between monthly fluid volume and luminous phenomena occurred (but systematically delayed over time) up to 300 km from the injection site. (The luminous phenomena within 50 km began about 6 months after the injections when the net accumulation was about 20 million gallons.) For the Attica, Sanford, and Rangely sites that involved presumably less volumes per unit time, the association was evident only as far as 150 to 200 km. In addition, the onsets of luminous phenomena around Attica, Sanford, and Rangely were delayed by two years while the onset of luminous phenomena around Derby and Hanford (which had histories of significant tectonic strain or fluid injection) was more immediate. If we assume that the amount of fluid injection and the status of the local stress determine the extent of expansion, then these differences between the sites would be expected.

Given the anistropic feature of local geology, equal rates or velocities of radial diffusion in all directions cannot be routinely assumed. Local geology should influence the direction of flow away from the injection site. To discern this direction, we constructed quadrants for each site by drawing N-S and E-W lines through its center. The numbers of luminous phenomena were inserted as a function of 50-km radial distances.

Luminous phenomena did not emerge homogeneously as a function of distance. For Rangely, 92% of the luminous phenomena for this period occurred (within 51 to 150 km) to the northwest of the site (the Uinta valley system) and constituted the classic Utah UFO display (Salisbury, 1974; Persinger & Derr, 1985). The primary direction for the occurrence of luminous phenomena around Derby changed over time; initially they appeared towards the northwest, then towards the end of the episode emerged at distances (>100 km) to the north and northeast of the site. The primary direction in the Attica episode was north to northwest, towards Lake Ontario.

The initial display of luminous phenomena near the Sanford Dam occurred within 50 km to the southwest about 8 months (August, 1965) after the flooding of the lake began. Starting 3 months before the anomalous earthquake (20 July, 1966; mb 3.9) to the southeast of the lake, the luminous phenomena moved to the southeast. The movement continued in this direction and culminated in the Wellington, Texas UFO flap of March, 1967 (about 150 km southeast of the lake at which time it was less than one-half filled). The prominent direction of luminous phenomena around Hanford during the period of analysis was to the west and northwest as far as 150 to 200 km and to the southeast for about 50 km.

If luminous phenomena observed at distances of up to 300 km from the injection site were associated with a travelling strain field accompanying hydraulic pressure transients, then some process in addition to radial diffusion may have facilitated the propagation. We suggest the following mechanism. Within a permeable geological basin [which can be 100 to 200 km wide and several hundreds of km in length (Costain, *et al.*, 1987)] that is tectonically stressed close to failure, a small change in fluid pressure initiates a strain field. The energy may be quite small since triggering of earthquake swarms can occur by (reservoir-induced) changes in water level of less than one meter (<0.1 bar; Costain, *et al.*, 1987).

All or most of the energy which propagates the process that generates luminous phenomena for these extraordinary distances is derived from the near-failure crust. As the strain wave moves, the collapse of the immediately surrounding stress field towards the radially diffusing wave constricts the spatial dimensions of the wave. The resultant "strain bolus" utilizes the stored anterograde stress as it moves away from the retrograde areas of less stress. Consequently the ultimate distance that the strain bolus (or an aggregate of these processes moving within a field) travels would be a function of the diameter and homogeneity of near-stress failure in the regional crust. Local directions of groundwater flow, orientations of fractures, and the distribution of strata within which static fatigue has been induced due to hydration of the silicon-oxygen bonds would affect the often tortuous directions of these quanta of strain.

The luminous phenomenon, as a singular event, would be a highly energetic process that would reflect the extreme collapse of the stress field into the strain bolus. The expected spin and vortical movements that would be induced by this collapse would encourage the creation of rotating, time-varying magnetic fields. The phenomenon created would be sufficient to generate several components of the electromagnetic spectrum and to contain constituents of normal rocks (e.g., silica, alumina, manganese); these patterns have been observed (Persinger, 1984). The probability of emergence of all or part of this strain bolus from the ground (and hence observation and report by

the human observer) would be highest where the crystalline rocks extend to the surface and the pore pressure approximates the hydrostatic pressure at the depths of the propagating wave (< 10 km).

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Accepted September 10, 1993.